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A REPORT ON POSSIBLE SAFETY HAZARDS ASSOCIATED WITH THE OPERATION OF THE 0.3-m TRANSONIC CRYOGENIC TUNNEL AT THE NASA LANGLEY RESEARCH CENTER

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1. INTRODUCTION

The 0.3-m Transonic Cryogenic Tunnel (TCT) at the NASA Langley Research Center was built in 1973 as a facility intended to be used for no more than 60 hours in order to verify the validity of the cryogenic wind tunnel concept at transonic speeds. The role of the 0.3-m TCT has gradually changed until now, after over 3000 hours of operation, it is classified as a major NASA research facility and, under the administration of the Experimental Techniques Branch, it is used extensively for the testing of airfoils at high Reynolds numbers and for the development of various technologies related to the efficient operation and use of cryogenic wind tunnels.

Over the years, as a direct result of the changing research roles of the 0.3-m TCT, additions and modifications have been made to the physical equipment of the facility as well as to the procedures used in its operation.

The purpose of this report is to document the results of a recent safety analysis of the 0.3-m TCT facility. This analysis was made as part of an on-going programme with the Experimental Techniques Branch designed to ensure that the existing equipment and current operating procedures of the 0.3-m TCT facility are acceptable in terms of today's standards of safety for cryogenic systems.

2. GENERAL OVERVIEW

The 0.3-m Transonic Cryogenic Tunnel has been in operation since 1973 and in general its performance has been satisfactory. The tunnel operates at temperatures as low as 77K and at pressures up to 6 atmospheres absolute. It is cooled by injecting liquid nitrogen into a circulating nitrogen gas stream which is exhausted in a controlled way to compensate for the increased gas volume arising from the vaporizing liquid nitrogen.

The operation of the tunnel involves the storage of liquid nitrogen received from an outside supplier, the transmission of liquid nitrogen to the tunnel by pump and the exhaustion of gaseous nitrogen from the tunnel. In general these operations would be expected to lead to the potential exposure of personnel and equipment to the following hazards:

(1) Asphyxiation due to oxygen deficiency.
(2) Freezing of human tissue due to excessive cold.
(3) Failure of metal parts and materials which are not suitable for use at low temperatures.
(4) Over-pressurization failures due to the vaporization of trapped liquid nitrogen.
(5) Failures due to differential contraction and expansion.
(6) Fires and explosions caused by condensed atmospheric air coming in contact with combustible material.
(7) Fog formation and icing due to escape or intentional release of cold fluid.
(8) Exposure to excessive noise.
(9) Incorrect installation of cryogenic equipment.
(10) Inadequate training to alert personnel on hazards which are alien to normal experience.
(11) Inadequate provision of rescue equipment.

My general findings in regard to the above safety points were that, whilst the personnel responsible for the tunnel were aware of most if not all of the points, they were not in all instances taking active steps to ensure the elimination of the hazards.

It was noticeable for instance that several lines, which could be chilled to the condensation temperature for air, were insulated with rubber-like flammable material. A test confirmed that this material would burn in air let alone in the oxygen enriched air which normally arises when air is partially condensed. Furthermore, the possibility of cold liquid nitrogen impinging on mild steel components was noted in several areas. The incorrect installation of several cryogenic valves was also noted.

The highly dangerous asphyxiation hazard had been in the main competently dealt with but even here the safety measures were not completely foolproof. Noise would appear to present no problem as personnel normally do not enter the tunnel room when the unit is operational, but if in emergencies someone does have to enter the area it would probably be desirable for him to have ear protection.

The problems of contraction and expansion appear to have been adequately dealt with. I found no unprotected points where liquid could be trapped.

Time did not permit me to investigate the methods used to train new personnel but the level of understanding of the people I met on the site suggested that this area had been well covered. Because cryogenic accidents tend to occur infrequently, workers tend after a time to think the hazards they have been warned about never really arise. For this reason, retraining is important and, in this connection, talks by an outsider such as those I gave at Langley can be of considerable value.

Breathing equipment was available for the purposes of rescue. Because very speedy action is called for in cases of asphyxiation, I would also recommend having one resuscitator on the site.

3. PRODUCT RECEIPT

Liquid nitrogen is purchased from an outside supplier and delivered to the site storage tanks by tanker which is connected to a delivery point

located outside the storage tank compound. This point was found to be unlabelled and it is of prime importance that a label be provided. I also found that there was no attempt to check that the correct product was being delivered and, whilst it would not be disastrous if some oxygen (say) instead of nitrogen was fed to the tunnel, I think it desirable for a monitor to be fitted at or near the supply point to preclude this sort of error.

4. LIQUID NITROGEN STORAGE AREA

4.1 Storage Tanks - Cryogenic Protection

The storage comprises 2 x 28,000 US gallon tanks which appear to be of the vacuum insulated type having a powder filling.

The settling of the powder in the vacuum space of such tanks can lead to the top of the cold inner tank being able to "see" the mild steel outer shell and if this happens the transfer of heat by radiation can cool the outer shell to such an extent that it embrittles and cracks. As the tanks are fairly old, personnel should check that this is not happening by observing any excessive frost formation on top of the tanks. If it is suspected that the powder has settled, experts should be called in to top it up. If a crack is allowed to develop this will lead to loss of vacuum and excessive heat inleak and will call for a very expensive repair.

Several vents are so located that they spray liquid nitrogen directly on to the top of the outer mild steel shells which could lead to cracking of an outer shell. One of the worst offenders is the big T vent which often overspills when liquid is being received from the tanker. Some of these, in particular the priming vent from the pump supplying liquid nitrogen to the tunnel which is said to discharge heavily upon occasion, could fairly easily be relocated to discharge between the tanks in the location of the present vent for precooling the nitrogen line to the tunnel. As it would be difficult and costly to relocate all the vents on top of the storage tanks, it is recommended that an aluminium shield be provided to direct liquid away from the top of each tank.

4.2 Lines and Valves

Insulation has been removed from a portion of the main filling line by people walking on it. A proper step should be provided.

The main filling valves 3096M and 3097M are almost inaccessible. To really correct this would call for major pipeline rearrangement but some improvement could be obtained fairly easily by swinging the valves 45^{o} to the vertical position - at this angle they would still function satisfactorily from the cryogenic viewpoint.

Several cryogenic valves, e.g. 3091M, 3098M, 3099M, 3100M, 3090M and 3061M, are located horizontally and should be raised to the vertical or near vertical position.

4.3 Liquid Nitrogen Vaporizer

For satisfactory and efficient operation, a vaporizer of the type installed should have a head of liquid at its lowest point to give the maximum differential head obtainable between the inlet and outlet sides, as this is the driving force for circulation. It was observed that the liquid feed line to the vaporizer had not been insulated. This line should be insulated right up to the point where it enters the vaporizer.

Furthermore, the vaporizer control valves 3094M and 3095M are badly located and they should be moved to about 45^{o} from the vertical. The small bottom draw valve to the vaporizer, 3093M, should be rotated 45^{o} towards tank A to improve operator access.

4.4 Tank Pressure Control Mercoid Switch

In its present location it is very difficult to adjust the setting of this switch - it could usefully be swung round and forward.

4.5 Barton Level Gauges

These are at present located low down in an area which could easily become fogbound due to any leaks from the gland on the nitrogen circulation pump to the tunnel. They should be raised and brought forward.

4.6 Temporary Test Station

The present arrangement is such that anyone opening valve 3071N would almost certainly be asphyxiated with nitrogen. This valve should be blanked off or capped and if this unit is going to be used it would be better to move it to an area where there is more positive ventilation.

4.7 Ventilation

The fact that the storage area is bounded by high walls with only a few openings means that ventilation is restricted and that fog, once formed, will be slow to disperse. Operation of the vaporizer fan would assist but it might be better to establish more openings in the walls as a safeguard against asphyxiation and fog formation.

Under high vent conditions liquid nitrogen splashing along between the tanks could vaporise at the far end of the enclosure and produce gas which might be sucked into the ventilation system of the nearby NTF pumphouse. Whilst I am told that an oxygen monitor is going to be provided in the pumphouse, arrangements should be made to warn anyone in the pumphouse in the event of a big spill.

4.8 Housekeeping

It is undesirable to use cryogenic tank areas for general storage. Metal staging and girders which I saw stored where people might want to walk or run between the tanks could prove very dangerous in the event of a spill leading to fog. Wooden boxes were also being stored as well as drums of acetone and other chemicals. There was also quite an accumulation of leaves.

The concrete floor needs a good brush and, where necessary, broken concrete should be made good, preferably using high alumina cement whose extra cost should be justifiable as it would give a longer service life than ordinary concrete.

5. LIQUID NITROGEN TRANSFER TO TUNNEL

Transfer is accomplished using a 150 gal/min pump yielding a pressure of about 180 psi.

For satisfactory operation the pump should be properly cooled down before it is started up and it should run with an adequate NPSH to avoid damaging cavitation.

Cold liquid giving ideal suction conditions is best obtained by depressurizing and repressurizing the storage tank. This is done in the case

of Tank A but not in the case of Tank B which is used to provide nitrogen gas for purging. I was told that the pump worked well on Tank A but not so well on Tank B and there might therefore be a case for having a separate system for generating purge gas so as to optimize pumping conditions from Tank B.

In view of the asphyxiation hazard, it is important that there should be no flow of nitrogen to the tunnel when it is shut down. At present a manually operated double block and bleed system with four vents prevents this but I am concerned that this system could be overridden in error and that stop valves at the tunnel nozzles, which could easily leak, would be the only remaining safeguard. Automation of the control valves at the pump would reduce the hazard by giving an indication of valve settings in the control room but, in addition to this, a fully automated double block and bleed near the line to the nozzles and closing off both the liquid feed line and the return line with an adequate vent in between leading outside the building could usefully be provided.

6. TUNNEL

For much of the time the tunnel is operated at pressures up to 6 atmospheres. Above about 1.6 atmospheres the temperature will be too high to condense air. However, during startup and shutdown, and during any periods of low pressure operation, the possibility that air may condense leading to a potential combustion hazard should be recognised.

6.1 Insulation

Several instances were noted of lines on which air might condense having rubber-like flammable insulation. It would be better to replace this with non-combustible insulant. The main tunnel insulation is purged with nitrogen - a feature which should go a long way to preventing air and moisture condensation and maintaining the efficiency of the insulant.

6.2 Cryogenic Valves

Several of the cryogenic valves controlling the tunnel are wrongly located from the cryogenic viewpoint, e.g. 3061N, 3063N and 3062N. Ideally, all cryogenic valves should be located vertically or at a reasonably steep

angle to the vertical. This provides a gas seal which prevents cold liquid reaching the gland where it will cause frosting and seizure.

It was also noted that many of the cryogenic valves, e.g. 3062N and 3061N, are hydraulically operated and that hydraulic oil which could burn was leaking from their mechanisms. It is generally better to employ pneumatically actuated valves in cryogenic situations and this is recommended when a change becomes possible. Until this happens, every attempt should be made to collect the leaking oil in trays which should be cleaned out frequently to prevent oil accumulation.

6.3 Flooring

Oil dripping from the main fan bearings is damaging the floor at one end of the tunnel. It is not easy to think of a flooring material that would get round the problem. The simplest way would be to try to collect the oil in trays so that it never finds its way on the floor.

6.4 Labelling and Warning Notices

There is quite a complex line system around the tunnel but very few identification labels. Wherever possible labels with flow indication should be provided. Warning notices on the danger of asphyxiation should be provided at the larger tunnel openings and in the building itself.

Warning notices should also be provided near the roof vents.

6.5 Ventilation

Until the additional safeguards referred to in Section 5 have been implemented, it would be useful to have a small fan ventilating air through the tunnel when it is opened up.

6.6 Operation

The methods of operation were discussed and appear to be satisfactory. It is recognized that operation of the tunnel at higher pressures and lower temperatures makes it more difficult to vaporize liquid and a careful watch has to be kept against excessive accumulation of liquid within the tunnel. The importance of avoiding moisture formation in the tunnel is also appreciated and appropriate steps are taken to prevent this.

Sticking valves due to their having been wrongly installed may have introduced operational difficulties from time to time. The modifications referred to in 6.2 should get round this.

7. CONCLUSIONS

The fact that this unit has operated without serious incident since 1972 is a testimony to its general viability and to the quality and training of the personnel who have been associated with it. As a research tool, the plant has been designed to an unusually high standard - to meet rigorous industrial requirements in regard to operation and safety it could however be usefully modified here and there on the lines suggested in this report. As a visitor I was impressed by the efforts of staff at all levels to ensure that I was warned of tripping hazards and the like - visitors are so often neglected when it comes to safety.

8. RECOMMENDATIONS

From the viewpoints of operational viability and safety, some of the recommendations suggested in the report are more important than others. For this reason I have decided to present the recommendations as essential or desirable as indicated below:

(a) Essential

8.1 Identify product at liquid nitrogen filling point.

8.2 Check powder has not settled excessively in storage tanks.

8.3 Reposition easily moveable vents to direct liquid nitrogen away from the tanks.

8.4 Provide an aluminium shield at the top of each storage tank to prevent any remaining vents splashing liquid on to the outer shells.

8.5 Reinsulate the liquid nitrogen filling line at point of damage and provide a protective cover to prevent further damage by walkers.

8.6 Insulate vaporizer liquid feed line from storage tank outlet to vaporizer inlet.

8.7 Remove or completely blank off Temporary Test Station.

8.8 Remove trip hazards and stored materials from storage area.

8.9 Ensure NTF warned in case of major vent spill in storage area.

8.10 Provide fully automated double block and bleed system venting to outside at liquid nitrogen inlet to tunnel.

8.11 Replace rubber insulation wherever it is to be found on cold lines with non-combustible insulant.

8.12 Ensure that all cryogenic valves are located vertically or in the near vertical position.

8.13 Provide trays to collect oil where it occurs but do not allow oil in trays to accumulate.

8.14 Improve product identification and flow indication throughout plant.

8.15 Maintain an adequate procedure for training and retraining personnel.

(b) Desirable

8.16 Monitor product purity at the filling point to ensure that wrong product is not delivered.

8.17 Relocate liquid nitrogen filling valves to storage to improve accessibility.

8.18 Relocate Mercoid switch and Barton level gauges.

8.19 Improve ventilation in storage area by increasing wall ventilation.

8.20 Where broken, relay concrete in the storage tank area.

8.21 Automate pump control valves to facilitate remote operation from the control room.

8.22 Hydraulically operated cryogenic valves should be changed to pneumatic operation.

8.23 Provide a small fan to ventilate air through the tunnel when shut down and opened up.

8.24 Provide a resuscitator on the site.

8.25 Provide ear protection for personnel naving to enter the tunnel room when the tunnel is working.

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16 Abstract

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